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A field study conducted at Kidston Gold Mine, to evaluate the impact of arsenic and zinc from mine tailing to grazing cattle

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Abstract

The grazing trial at Kidston Gold Mine, North Queensland, was aimed specifically to assess the uptake of metals from the tailing and the potential for unacceptable contamination of saleable meat. Further aims included estimating metal dose rates and identifying potential exposure pathways including plant uptake of heavy metals, mine tailings adhered to plants and direct ingestion of mine tailing. It was found that of the 11 metals analysed (As, Zn, Co, Cd, Cr, Sn, Pb, Sb, Hg, Se and Ni) in the animal's liver, muscle and blood during the 8-month trial period, only accumulation of arsenic and zinc occurred. A risk assessment including these two metals was conducted to determine the potential for chronic metal toxicity and long-term contamination, using the estimates of metal dose rate. It was concluded that no toxicity or long-term contamination in cattle was likely at this site. Management procedures were therefore not required at this site; however, the results highlight percent ground cover and standing dry matter (DM) as important factors in decreasing metal exposure from direct ingestion of tailings and dust adhered to plants.

Keywords: Heavy metals; Tailing; Arsenic; Zinc; Bioavailability; Cattle; Risk assessment

1. Introduction

A common future use of mined land in Queensland, Australia is for pastoral activity and particularly cattle grazing. In order to ensure that transfer of contaminants such as arsenic from rehabilitated mine land does not lead to a health risk via consumption of meat, it is important that uptake processes are understood. A number of key aspects including metal bioavailability, metal dose rate and exposure pathway are essential in developing a risk assessment procedure for use in mine waste management at development and rehabilitation stages. This field study forms an integral part of a larger study aimed at addressing all aspects of this risk assessment procedure.

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Criteria for the rehabilitation of mine sites have become more stringent with the increasing awareness of the potential for detrimental effects on the environment and human health from exposure to metals liberated in mine waste. A key issue in Australia is the utilisation of mined land for future pastoral activity. In particular, the state of Queensland faces an increasing need for such criteria, as it supports economic mining and livestock industries.

Following mining of the ore, extraction or separation of the economic item is required. Usually crushing and grinding is necessary to improve surface area and to allow efficient extraction by reagents or separation. The resulting waste products on a mine site, based on open cut mining are waste rock and tailing, usually held in separately constructed landforms or structures, which minimise their erosion and transport of contaminants. Key contaminants present in waste from base metal mining and other sulfidic deposits are metals (e.g. Cd, Cu, Pb, Zn) and metalloids (As, Se, Sb, Bi). Because processed mine minerals are finely divided, there is a potential risk that such materials may find their way through the environment and food chain to animals/humans.

The strategic framework for mine closure of ANZMEC/Minerals Council of Australia (2000) identifies: ''to establish a set of indicators which will demonstrate the successful completion of the closure process'' and '' the need for targeted research to assist both government and industry in making better and more informed decisions''.

A risk assessment process underlies the risk management strategies adopted. One of the key aspects of risk assessment is the bioavailability of contaminants. In the absence of specific bioavailability data, this is assumed to be 100%. Data on bioavailability of toxic elements, particularly arsenic, from tailing in Australian conditions are lacking. This program in its larger sense, is developing a physiologically based pharmacokinetic model in animals which will provide bioavailability data for various metals and metalloids, from mine tailing and other mining waste in order to permit realistic risk assessment of rehabilitated mine facilities under Australian conditions and quantitative indicators for mine closure. The model is being generated by comparing a laboratory animal model (rat) to both cattle (most common on farms) and pigs (human similarity) given mine tailing in a controlled environment. From this, bioavailability and accumulation patterns of various metals and metalloids will be determined.

A second key aspect of risk assessment is the ability to estimate a realistic exposure, or dose rate, of the mine waste to the grazing cattle over a set period of time. Hence, grazing trials conducted directly on rehabilitated tailing facilities have provided valuable in situ information on heavy metal dose rates and associated accumulation. One such trial was conducted at Kidston Gold Mine, Queensland, during 2000.

Kidston Gold Mine is situated 260 km southwest of Cairns or approximately 280 km inland from Townsville, at an elevation of around 540 m. The climate is subtropical with a distinct wet season between November and March.

The mining operation at Kidston Gold Mine commenced in 1984, using a carbon-in-pulp extraction process, with the waste fines being disposed to a tailing dam now covering an area of approximately 300 ha. The economic ore body was depleted in mid-2001, at which time the mine was closed. The tailing dam has been decommissioned and direct revegetation of the surface (without capping) has been undertaken over a proportion of the dam at present. The revegetated areas were planted with tubestock tree and shrub species and direct sown pasture grasses, predominantly Rhodes grass (*Chloris gayana*) and Couch grass (*Cynodon dactylon*).

At the end of mining, a return to grazing has been nominated as the preferred land use by the local landowner for the tailing dam. Given the potential for metal accumulation within grazing animals, either through metal uptake in plants and subsequent ingestion or by direct ingestion of tailing, the mine must be confident that metal contamination will not attain unacceptable levels. Hence, the outcomes generated by this trial are directly beneficial to Kidston Gold Mine and other stakeholders, whilst comprising an integral part of a larger study, which aims to develop a risk assessment procedure for utilisation at the design and rehabilitation stage of Australian mine practice.

The prime focus of this study was, therefore, the uptake of metals and metalloids from the tailing and the potential for unacceptable contamination of saleable meat from cattle grazing on the rehabilitated land. Other questions being addressed included estimating metal dose rates and quantifying potential exposure pathways including plant uptake of heavy metals and metalloids, and direct ingestion of mine tailing.

2. Methods

2.1. Trial design

In this trial, uptake and potential contamination was tested under a high intensity of grazing, whereby a maximum exposure to the tailing was created. The design was chosen to provide outcomes from a worst-case scenario based on the proposed land use, cattle grazing. Management procedure to reduce potential risk, if required, would then be proposed based on these outcomes, as opposed to exposure based on a lighter grazing pressure under normal farming practices. Therefore, if contamination did not occur during the trial using heavily stocked paddocks treatment groups of cattle, further investigations would be unwarranted.

Three pasture treatments were established to examine the accumulation of heavy metals and metalloids in selected organs and tissue of grazing cattle. The treatments included a control paddock situated approximately 50 km away from Kidston Gold Mine (referred to here after as the 'Background Paddock' (BP)), not affected by mining activities, and two paddocks within the tailing dam rehabilitation area with different levels of acid-soil conditions.

2.2. 'Background Paddock' treatment

A background treatment was selected to represent the grazing country surrounding Kidston Gold Mine. The paddock was selected on a property approximately 50 km from the mine, with no contamination to wind-blown dust from mining activities. The background treatment unavoidably differed from the tailing treatment paddocks in soil type pasture species and potential sustainable stocking rate. The tailing pasture is unique in the region, being artificially created as a result of the mining process. However, the inclusion of a background treatment was necessary as no baseline levels of heavy metals and metalloids and their impact on grazing cattle were available for the grazing country surrounding the mine. Soil and pasture samples were collected to ensure that the BP was not affected by contaminants, including heavy metals and metalloids, due to livestock management practices.

2.3. Tailing dam treatments

Two adjacent treatment paddocks were established at the southern end of the tailing dam to represent differing levels of soil oxidation. Tailing paddock 1 (TP1) was a 5 ha paddock incorporating an area of known acid-soil conditions and lower potential pasture DM yield (Table 1). Tailing paddock 2 (TP2), a 4 ha paddock, was selected to represent the predominant conditions of the tailing dam. TP2 did not contain significant areas of strongly acid-soil conditions and as a result potential pasture DM yield was higher.

2.4. Grazing management

Oral ingestion is generally considered to be the major route of exposure to metals and metalloids.

Table 1
Mean arsenic and zinc concentrations (mg/kg) in the three treatment paddocks (the range is also given for TP1 and TP2)

		Arsenic	Zinc
BP	Average	B 15	36
TP1	Maximum	1120	1100
	Average	425	717
	Minimum	27	110
TP2	Maximum	1760	3430
	Average	470	1557
	Minimum	150	630

Three possible pathways exist for cattle to ingest heavy metals and metalloids from the tailing dam, viz. (1) by grazing pasture plants that have accumulated heavy metals in their leaf and stem tissues, (2) by directly ingesting contaminated soil that has adhered to pasture plants or from the soil surface and (3) by either deliberate direct ingestion of tailing material or accidental ingestion during grazing. To maximise the potential exposure to tailing material and associated ingestion, a grazing regime was implemented to limit the animals in grazing area. An electric fence was used to restrict the area available for grazing in each tailing paddock so that the existing pasture would be heavily grazed over a relatively short period of time (2 months), thereby maximising the potential for ingestion of tailing material within the experimental period.

Due to the low palatability of the dry season pastures at the beginning of the experimental period, some supplementary feeding was required. It was decided that urea and molasses be fed at approximately 1 kg per day per head to stimulate consumption of the dry pasture. Supplementary feeding was continued until late October 2000. The supplement was sampled to exclude it as a source of heavy metal contamination (data not shown).

The grazed area was restricted to 0.8 ha for the first 2 months of the experimental period, with each paddock having similar standing DM. Due to low consumption of the grasses over this period, it was decided to slash the existing 0.8 ha area to encourage fresh regrowth.

To ensure that sufficient pasture was available for stock, the restricted grazing area was enlarged in November. The restricted area tripled in TP1, to become 2.4 ha and doubled in TP2 to become 1.6 ha based on the DM yield of each of the paddocks.

2.5. Chemical composition of soils and plant species

Prior to the introduction of cattle to the treatments, paired soil and plant samples were collected across the two treatment paddocks. Soil samples were collected at 400 m^2 grid intervals using transect lines. Approximately 120 soil samples were collected from each tailing paddock at 0–10 cm depth and composite samples from each tailing treatment were then analysed for metal and mineral nutrient concentrations with inductively coupled plasma mass spectrometry (ICP/MS). Ten random soil samples were also collected from the BP. Samples collected from across the paddock were bulked prior to analysis to determine metal concentrations.

Pasture grab samples collected from each soil-sampling site prior to the commencement of grazing were also analysed for metal and mineral nutrient concentrations. Samples of the two main pasture species found on the tailing paddocks (Rhodes and Couch grasses) and BP (Black Spear Grass) were bulked for each paddock.

2.6. Washed/unwashed plant material

To determine the percent contribution of metals and metalloids from adhered particles, compared with that available in the plant tissue, concentrations of metals and metalloids of each composite or individual plant sample were measured washed and unwashed. ‘Washed’ samples were soaked in 10% HCl overnight (16 h) before being rinsed five times in Milli-Q water in order to remove all adhered tailing material. Samples were then dried at 90 °C for 24 h.

Using estimates of plant metal concentrations and adhered plant soil metal concentrations, combined with estimates of direct soil ingestion, total dose rates could be estimated for each treatment. Dose rates for plant metal and plant adhered soil metals were calculated by using an estimate of DM intake per day (2.5% of body weight (b.w.) per day) and the average weight of the animals during the trial (331 kg) (Table 3).

2.7. Processing and analysis of plant samples

Both ‘washed’ and ‘unwashed’ plant samples after being dried were homogenised using a food processor followed by and a small coffee grinder to obtain a finely divided specimen for analysis. All samples (1 g) were digested in 1 ml of nitric acid in a closed system for 4 h in a boiling water bath. Samples were then diluted to 10 ml with Milli-Q water before relevant multi-elemental analysis.

2.8. Experimental animals

Fourteen, approximately 2-year-old, Brahman cross-steers were purchased locally by Kidston Gold Mine (GGM) on 29 July 2000. All animals were initially transported and held on the BP property for a 2-week period of acclimatisation. Subsequently, on 15 August 2000, five cattle were placed within each of the two tailing dam paddocks, and the remaining four in the BP. All animals were ear-tagged for identification.

The grazing trial continued for approximately 8 months (237 days). Periodic samplings of blood, and biopsy of the liver and muscle from the animals were conducted to monitor the accumulation of metals.

2.9. Animal sampling

Samples of blood, biopsy of the liver and muscle for the determination of heavy metal and metalloid concentrations were taken from experimental cattle four times during the experimental period, on days 0, 65, 110 and 172. During all sampling events, animals were weighed to monitor weight change, and assess whether their health was being affected by the trial design or by the sampling procedure. It was considered that sampling background treatment animals at all biopsy schedules was unnecessary. Therefore, these animals were sampled only during the first and third sampling events.

The experimental animals were slaughtered at the Rocky Creek Abattoir, Tolga, on 6 April 2001. At necropsy, blood, muscle, urine and other tissues including heart, liver, brain, tongue, kidney, spleen and gut (tripe) were collected.

2.10. Metal and metalloid analysis

Liver, muscle and whole blood from each of the four biopsy events, along with all samples collected at necropsy, were digested in nitric acid before ICP/MS analysis by Australian Government Analytical Laboratories (AGAL) in Pymble, Sydney.

3. Results

A number of heavy metals and metalloids were analysed within the tailing (soil), plant material and animal blood, urine and tissue, in this grazing trial. In this report, only the arsenic and zinc data were represented.

3.1. Analysis of tailing material

Even though there are no guideline levels to date for disturbed mine land, both TP1 and TP2 indicated arsenic concentrations above the NEPC Health Investigation Levels (HILs) guideline levels for residential soil where minimum exposure is expected (NEPC, 1999). The average zinc concentration was higher in TP1 than in TP2. However, both were markedly low compared with all HIL for residential soils. These patterns are not unexpected, as zinc may not be associated directly with gold bearing ores, whereas arsenic is through its presence in arsenopyrite.

Arsenic levels exceeding the paddock average were more extensive in TP1. Comparatively, TP2 had a slightly higher arsenic average and concentration range. The upper range value represented only one relatively small area in this paddock (Table 1).

3.2. Analysis of plant material

In order to detect any possible relationships between metal and metalloid accumulation and the pasture condition, periodical assessments were conducted on the two tailing dam paddocks (Table 2). The standing DM figures indicate that available pasture was similar for the two paddocks initially and after the paddocks were slashed and extended in November. Both paddocks experienced noticeable regrowth after the slashing event in November, which accelerated during the seasonal rain events in December and January. As a result of the larger area available in TP1 and the rapid regrowth, the available DM became significantly higher in this paddock toward the end of the trial in March 2001 (Table 2).

Table 2
Total standing DM yields, litter yields and percent cover for the pasture in TP1 and TP2 at the sampling intervals during the trial period

	TP1			TP2		
	August 2000	November 2000	March 2001	August 2000	November 2000	March 2001
Standing DM (kg/ha)	4220	690	990	4500	1250	750
Standing DM (paddock total in kg)	3376	1658	2376	3600	2000	1200
Litter (kg total)	Not done	1224	1920	Not done	992	1904
Cover (%)	75	58	59	82	74	69

As expected, the litter values increased markedly in both tailing paddocks as a result of the slashing in November (Table 2).

Even though arsenic concentrations in the grasses found on the tailing paddocks were markedly higher than the grass found on the BP (Fig. 1), the contribution from metals in the grass to the estimate of total dose was relatively low (Table 3). Comparatively, the extent of zinc concentrations found in the two tailing paddock grasses was also higher compared with the background grass (Fig. 1), however, the contribution to the estimate of total dose rate was relatively high (Table 3).

More specifically, the contribution from the different grass species found on the tailing paddocks was not significantly different for either arsenic or zinc (P B 0.05).

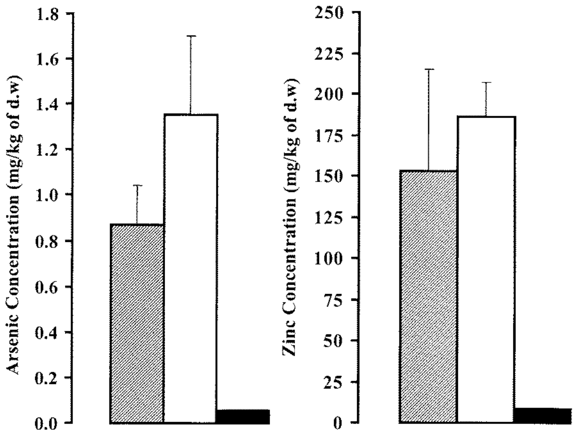

Fig. 1. Metal concentrations (mean 9 SE) in Rhodes grass (C. dactylon) (b) and Couch grass (C. gayana) (I) from the tailing paddocks compared with metal concentrations in Black Spear Grass (Heteropogon contortus) (j) found on the BP. Mean values for arsenic and zinc are not significantly different for Rhodes and Couch grasses (P B 0.05).

3.3. Animal sampling

The mean arsenic concentration found in the liver of the background animals remained constant during the trial period. Arsenic accumulation observed in the liver of the two tailing paddock animal groups between the second (65 days) and third (110 days) biopsy events were statistically significant (P┘ 0.05). From this point onwards, arsenic accumulation in both tailing paddock groups had reached a plateau, and no statistically significant change in concentration occurred.

The mean zinc concentration found in the liver of the background animals increased gradually due to accumulation after the second biopsy event (65 days), resulting in the zinc concentration at necropsy being statistically different (P B 0.05). Zinc accumulation in the liver was significant (P B 0.05) for the animals in TP1 between the second (65 days) and third (110 days) biopsy events, after which no significant accumulation occurred. The increase observed in the zinc concentrations in the liver of animals in TP2 during the trial period was statistically significant (P B 0.05), represented by the gradual accumulation pattern during this period. If a line of best-fit is used to extrapolate this accumulation rate for animals in both tailing paddocks, an estimate of approximately 2 years is expected to result in a breach of the maximum permitted concentrations (MPCs) for zinc in liver tissue for animals maintained under these conditions.

Table 3
The estimated dose rate (mg/kg b.w.) of metals from plant tissue, adhered tailing (soil) dusts and from estimated direct ingestion of tailing (soil). A total dose rate based on these estimates is also given.

	Plant tissue (A)	Plant dust (B)	1 kg tailing (soil) (C)	EDR (A┐ B┐ C)
BP				
As	B 0.01	B 0.01	0.05	B 0.07
Zn	0.22	0.37	0.11	0.70
TP1				
As	0.03	0.03	0.85	0.91
Zn	2.40	3.07	2.27	7.74
TP2				
As	0.03	0.01	1.12	1.16
Zn	5.93	5.67	4.23	15.83

Arsenic concentrations in the urine, muscle and all major organs were significantly different (P 5 0.05) for animals in TP1 and TP2 compared with those in the BP at the necropsy (237 days) (Fig. 3A). The arsenic concentration in the gut tissue from animals in TP1 was also significantly different (P 5 0.05) from those animals in the BP. A general pattern whereby arsenic concentrations in the kidney, gut, spleen and heart were all higher in the animals in TP1 compared with TP2 (Fig. 3A). The mean zinc concentrations found in all treatment groups at necropsy were similar in the urine, muscle and all organs except the kidney. The mean zinc concentration in the kidneys of animals in TP2 was found to be higher than the mean zinc concentration found in both the animals in TP1 and the BP (Fig. 3B).

4. Discussion

The main focus of the Kidston grazing trial was to study the accumulation of heavy metals and metalloids within the tailing and their potential for contamination of saleable meat as a result of cattle grazing. The potential pathways of metal and metalloid contamination include ingestion via plant material and the adhered tailing dust, and ingestion of tailing material directly. The relative contribution of these pathways can depend on the metal involved. Thornton and Abrahams (1983) reported arsenic within plant tissue as being a minor contributor to metal ingestion in cattle, compared with zinc. Tailing containing metals are adhered to the plant tissue and are ingested during grazing, or may be ingested directly from the ground as a consequence of normal grazing behaviour, or as a deliberate behaviour known as ''pica''. This behaviour usually occurs in animals lacking essential dietary elements (Fraser, 1974; Beaver, 1994). Also, in areas of exposed tailing, evaporites containing metals and metalloids are able to form, and deliberate ingestion by cattle of these evaporites has been reported (Noller et al., 1997). Such ''direct ingestion'' of soil (not associated with plant material) may be up to 10% of the daily DM intake, equating to as much as 1 kg of soil per day (Healy, 1968; Thornton and Abrahams, 1983).

The Kidston grazing trial was designed in such a way as to create maximum exposure (worst-case scenario) to the tailing material. The Australian└New Zealand Food Authority (ANZFA, 1994) guidelines were not breached for any of the metals analysed in this trial. For this reason, it was not necessary to make recommendations for appropriate minimisation or management procedures specifically for the Kidston site. However, accumulation of arsenic and zinc did occur in the animal tissue during the course of the trial. For this reason, predictions for the potential for contamination of each of these two metals will be given. The first step in this assessment involves comparing an estimated likely dose rate (based on a assumed ingestion rate of plant material and tailing ingestion) to a dose rate known to cause chronic toxicity, in order to assess the potential health risk during the animals were exposed to the trial period. The potential for acute toxicity was ruled out prior to the trial commencement, having considered the metal and metalloid levels in the tailing material, and the likely metal bioavailability based on previous work (Ng and Moore, 1996; Ng et al., 1998; Freeman et al., 1991, 1992, 1994). The second step evaluates the tissue analysis results at necropsy and the rate of accumulation in the liver in order to determine whether contamination occurred during the trial period, and to assess the potential for future contamination.

4.1. Arsenic accumulation

Previous work involving arsenic (lead arsenate) given to cows at dose rates up to 4.68 mg/kg b.w. resulted in no adverse affects (Marshall et al., 1963). Comparatively, the estimates of metal dose rate (EDR) (calculated by adding the individual estimated dose rates from plant tissue, plant dust and tailings material) for TP1 (0.91 mg/kg b.w.), TP2 (1.16 mg/kg b.w.) and the BP (5 0.07 mg/kg b.w.) are considerably lower, coupled with a potentially lower bioavailability. Hence, it can be concluded that animals grazed under these conditions would not be at risk of chronic arsenic toxicity.

It is well understood that a consequence of exposure to heavy metals such as arsenic is accumulation in organs such as the liver and kidneys (WHO, 2001). From the result (Fig. 2A) representing accumulation of arsenic in the liver, accumulation is observed between 65 and 110 days after trial commencement for both tailing treatment groups. The rate of accumulation reached a plateau at this point for both groups of animals grazed on the tailing paddocks. We can assume then that the estimated dose rates for TP1 and TP2 were sufficiently high to prevent complete clearance from the body. The dose rates were not, however, high enough to cause continued accumulation in the liver during the trial period, where we may have expected the levels to breach the MPCs set by the ANZFA (1994) guidelines. What is evident from this result is that the pattern of accumulation reflects the level of available pasture and hence the tailing exposure. That is, no accumulation occurred until the pasture was slashed in October, when a rapid rate of accumulation occurred, after which, accumulation reached a plateau when the seasonal rainfall after this period induced rapid pasture growth and associated tailing cover. This is consistent with earlier work done by Thornton and Abrahams (1983), who reported arsenic in soil being a more important contamination pathway than via plant material.

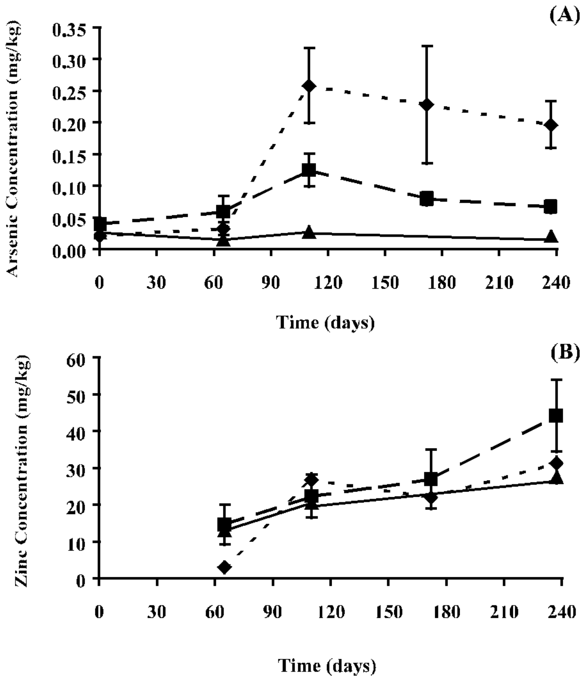

Fig. 2. Arsenic (A) and zinc (B) concentrations (mean 9 SE) found in the liver from the initial biopsy in August 2000 (0-day) through to the necropsy (237 days) in April 2001. Each treatment group is represented separately: TP1 ("), TP2 (j) and BP ('). The MPCs for arsenic in bovine liver is 1.0 mg/kg, and it is 150 mg/kg for zinc. Due to zinc contamination discovered in the liver samples from the first sampling event (0-day), all animals, including background, were sampled for liver during the second sampling event in October (65 days) to confirm zinc concentrations.

Even though the EDR for arsenic is greater in TP2, we see that arsenic accumulation reached a higher steady state in TP1. A number of related issues might be used to explain this pattern. Firstly, the higher mean arsenic concentration and maximum value in TP2 was influenced by a relatively small area of acid condition and associated elevated metal levels. Comparatively, TP1 contained relatively large regions of acid condition and elevated arsenic levels. Even though animals in TP2 experienced exposure to a higher maximum arsenic concentration, those in TP1 experienced more widespread exposure to high arsenic concentrations during the trial period. Complicating this further is the grazing pattern of the animals within these paddocks, as favouring certain areas would have influenced the exposure to tailings of different metal concentrations. Therefore, it is important to consider the patterns of metal concentrations associated with the mean levels, and also the possibility of animal behaviour biasing exposure, when defining contamination potential. Secondly, the higher arsenic accumulation observed in TP1 may represent a higher tailing exposure due to the lower standing DM and associated percent ground cover in this paddock. Furthermore, the dose estimate received from plant-adhered dust in TP1 was greater than TP2. This may be explained by the lower leaf litter in TP1 after the slashing event, which, when combined with a lower ground cover and standing DM per ha, may have contributed to the higher plant-adhered dust levels. Thirdly, the more extensive areas of acid condition in TP1 may have influenced the bioavailability of the metals within the tailing in this paddock.

Arsenic concentrations found in various other organs, such as kidney, gut, heart, brain, lungs and spleen at necropsy, were all higher in animals in TP1 than TP2, and both were higher than the background animals. These results confirm the accumulation observed in the liver. However, arsenic accumulation in the muscle was not higher in animals in TP1 than those in TP2, even though both were elevated above the background level. This may be due to a dilution effect in this tissue compared with smaller target organs such as the liver and kidneys.

Therefore, it can be concluded that even though arsenic accumulation occurred in the liver of both groups of tailing paddock animals, the estimated dose rate the animals were exposed to, and the associated accumulation was insufficient to cause chronic toxicity or any immediate or perceivable contamination.

4.2. Zinc accumulation

The EDR estimates for TP1 (7.74 mg/kg b.w.), TP2 (15.83 mg/kg b.w.) and the BP (0.7 mg/kg b.w.) are lower than levels reported to cause deterioration in the homeostasis of calves (≥ 20 mg/kg b.w zinc chloride) (Stake et al., 1975). Hence, coupled with the relatively low expected bioavailability of the tailing material, no chronic health effects were expected. To evaluate whether long-term exposure to zinc could cause contamination, the accumulation for zinc (Fig. 3B) in the liver was assessed carefully.

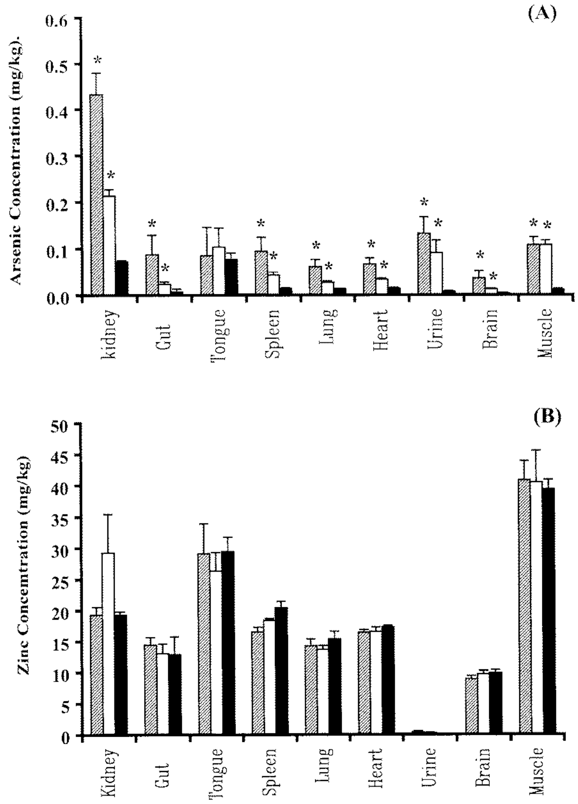

Fig. 3. Arsenic (A) and zinc (B) concentrations (mean ± SE) for all major organs, muscle and urine, collected during slaughter for TP1 (b), TP2 (I) and BP animals (BG) (j). The current MPC set for food by ANZFA for arsenic in bovine products is 1.0 mg/kg, and it is 150 mg/kg for zinc. Asterisks indicate where means differ significantly (P < 0.05) from the BG mean.

The liver zinc concentration reflects a rather different pattern of accumulation during the trial period. The gradual rate of accumulation for all treatment groups observed may indicate that plant metal content, and not tailing exposure associated with pasture condition, is the determining factor affecting metal exposure. That is, the consistent ingestion of pasture containing zinc may be a more important factor than the level of tailing exposure related to available DM and associated ground cover. If so, this would support comments by Thornton and Abrahams (1983), suggesting plant ingestion in cattle is more important than soil ingestion for zinc contamination for various areas studied in the United Kingdom. More specifically, these results indicate accumulation in the animals in TP1 and the BP occurred at approximately the same rate. This is supported by the similar tissue and urine concentrations at necropsy for these two treatment groups. This would suggest that both animal groups were exposed to zinc levels higher than those in the area where the animals were previously grazed. Also, the similarity in accumulation rate between TP1 and the BP animals suggests that the zinc within the tailing material, even though much more concentrated than the background soil, is not highly bioavailable. Even though a slightly higher rate of zinc accumulation was observed in the liver in TP2, possibly reflecting the higher estimated total dose rate for zinc in TP2, liver zinc concentrations at necropsy were not significantly different for TP1 ($P < 0.05$). Also, there was no significant difference in tissue or urine zinc concentrations (excluding liver) between the BP animals and the two tailing groups at necropsy. This also supports the earlier statement that even though animals in TP2 were exposed to a higher estimated dose rate of zinc than those in TP1, this was not reflected in the tissue accumulation due to the low availability of the zinc within the tailing materials.

Even though gradual liver zinc accumulation did occur in TP2 above background levels at the end of the grazing trial ($P < 0.05$), it is anticipated, based on extrapolation of the accumulation curve, that the MPC for liver would be breached after approximately 2 years, assuming the rate of accumulation continued under these conditions. It is expected that under a more realistic grazing intensity, the tailing exposure and associated estimated dose rate would not permit excessive contamination even over an extended grazing period.

4.3. Management considerations

None of the metals analysed during this trial, including arsenic and zinc, were considered a risk for contamination under the worst-case grazing scenario designed; hence, no immediate recommendations for the trial were needed. However, there were a number of considerations that will be discussed. Such considerations relate to the exposure pathways outlined above and ways in which exposure can be limited to reduce the potential for contamination.

Firstly, it must be made clear that a proportion of the metal dose is received from the plant material. Even though the bioavailability of specific metals from plant material may be low, species chosen for remediation of tailing should be those that do not accumulate metals in excessive concentrations. The adaptability of the grass species to tailing material, their suitability to the environment and pasture needs are important considerations. However, their ability or inability to accumulate metals should also play a role in the design stage of tailing dam revegetation. Even though metal levels for both grasses exceed those in the BP, there was no significant difference between the arsenic or zinc concentrations for two grass species. Hence, it can be concluded that neither of the two main grass species tested on the tailing dam magnified the potential for contamination beyond the other. An extensive trial using a wide range of grass species would be necessary to determine whether other species less likely to accumulate metals exist.

Secondly, the percent ground cover over the tailing material is an important consideration when attempting to limit the risk of tailing exposure. The areas of known acid condition in TP1 reduced the standing DM and associated percent ground cover consistently over the trial period. This may potentially have increased the risk of direct ingestion of tailing material within this paddock. Tailings in areas of known acid condition are often associated with elevated metal and metalloid levels due to the presence of soluble bioavailable constituents. These areas of exposed tailing material are likely to contribute to an increase in adhered dust on plant material.

Thirdly, the dust adhered to plant material potentially contributes a major percentage of metals to the diet. This further highlights the importance of maximising ground cover across the tailing facility to minimise the potential for tailing dust to accumulate on the plant material. This is especially important in the first few years after development, before accumulation of leaf litter on the surface of the tailing is significant. The difference in adhered dust concentrations between the two paddocks could be attributed to the notable difference in total standing DM and percent ground cover between the two tailing paddocks. The exposed areas in TP1, potentially responsible for the elevated dust levels, are areas of known acid condition, and hence elevated metal levels. The elevated plant-adhered dust levels may also be attributed to a higher splash effect from rain hitting the tailing material in the rain season or dust dispersion in the dry season, due to the lower standing DM and leaf litter in TP1. In order to reduce the risk associated with these exposed tailing areas, a number of management procedures could be adopted. As was done at Kidston, fertilising in the first few years during pasture establishment is essential to maximise percent ground cover. Follow up seeding may also be necessary to ensure consistent ground cover is maintained in the areas of known acid condition. Also, selecting species of grasses and trees that are acid-tolerant may be necessary to achieve suitable ground cover in these areas.

5. Conclusion

The grazing trial fulfilled its objectives by defining the uptake of heavy metals from tailing and the potential for unacceptable contamination of saleable meat at Kidston Gold Mine. From the estimations of dose rates for arsenic and zinc, it could be determined whether chronic toxicity may occur during long-term exposure to tailing of this nature. Based on the accumulation patterns in the liver and tissue analysis at necropsy, possible contamination could be determined and extrapolations allowed assessments of future contamination risk. For both arsenic and zinc, no immediate or long-term risk was perceived. Management strategies, even though unwarranted, were discussed and focused on the importance of maximising percent ground cover and standing DM, in order to minimise the potential tailing exposure. Further trials are currently under way on alternative rehabilitated tailing facilities with higher metal concentrations, to validate these findings. As no safety guidelines exist for rehabilitated mined land, such trials are imperative if we are to better understand the environmental risk associated with mine closure, and enhance the associated regulatory process. Investigation beyond bioavailability and accumulation, including specific measurements of metal species (Thornton, 1997), geochemical factors (Davis et al., 1992) and mixture effects may also be necessary to generate a more comprehensive risk assessment procedure.

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